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INFLUENCE OF END MILLING PROCESS PARAMETERS ON MICRO-HARDNESS OF LM25 ALUMINIUM ALLOY

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The surface integrity of the machined component plays a vital role on the mechanical property of aluminium alloys. This research focused on developing an analytical model in order to predict the changes in micro-hardness and microstructure of LM25 aluminium alloy Design of experiment (DOE) was adopted for determining the effect of end milling process parameters such as cutting speed (Cs), feed rate (f) and axial depth of cut (a_p) on arithmetic average micro-hardness (MH). The micro-hardness of the samples is tested with vicker's hardness tester. Desirability approach gives better accuracy of the result and the capability of predicting cutting process parameters. The optimum machining setting for single-objective optimization corresponds to Cs (81, 86 m/min), f(0,058 mm/rev), a_p(2,78 mm) gives higher value of MH (134,2 HV).

Key words: Aluminium alloy, casting, micro-hardness, scanning electron microscope (SEM)

INTRODUCTION

In manufacturing industry, milling process is widely applied for the material removal. The milled surfaces are meshed with other parts to achieve a better machinery behavior and also to improve certain functions like kinetic design [1]. The residual stress, micro-hardness and change in microstructure show a greater impact on the cracking initiation and propagation. [2]. However, the large strains were occurred with high strain stress due to complex machining process, coupling with a large amount of heat generated by dissipation of plastic work and frictional heating [3]. During the machining process analysis of induced surface integrity like phase transformation, residual stress, micro-hardness, grain size are very difficult due to complication of thermo-mechanical behavior of materials at high strain rates, and varies with process parameters [4,5].

Selection of process parameters traditionally does not guaranty the quality of the surface finish nor helps in attaining the higher material removal rate. So the process parameters selection should improve the efficiency of the machine and reduce production cost by effectively control the surface roughness [6]. Multiple problems can be resolved by adopting the Design of experiment methodology. In the field of engineering, the production cost can be effectively reduced by adopting certain techniques such as Central composite design (CCD), Taguchi and Box–Benkhen design (BBD) [7]. Investigation of process parameters on the responses can be effective done by statistical based approach response surface methodology (RSM). This method also helps in evaluating the interaction between the variables which is not done by adopting traditional experimental design [8].

Researchers have done various researches on non-ferrous alloys for improving the quality of the machine by computer numerical control (CNC) process [9,10]. However, no information is given on LM25 aluminium alloy in determining the process parameters. Hence the present study is focused on maximizing the micro-hardness by adopting response surface method (RSM) and desirability function (DF).

PRESSURE DIE CASTING OF LM25 ALUMINIUM ALLOY

Horizontal pressure die casting machine (120T technocrat) was utilized in fabricating automotive valve closer under an optimal solution. Coupling of standard short sleeve and maximum shot capacity is done on 6,9 kg aluminium. 400 tones capacity locking force was setup with an electric furnace at a maximum capacity of the melting temperature 2 000 °C with 1 000 litre. To find the optimal parametric solution the multi objective optimization technique was adopted. The Figure 1 depicts the various combination of intensification pressure; furnace temperature and shot velocity of the pressure die casted components.

The aluminium alloy LM25 was tested as per ASM standards and the chemical composition of the alloy includes Si 6,5 – 7,5; Fe 0,5; Cu 0,2 max; Mn 0,3 max; Mg 0,20 – 0,6; Ni 0,1 max; Zn 0,1 max; Ti 0,2 max , Sn 0,05 max, Al - balance.

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Figure 1 LM25 casted component

EXPERIMENTAL METHODOLOGY

Experimental design and procedure

Aluminium alloy LM25 was taken as a test samples with the diameter of 75 mm and 6 mm thickness. High speed steel (HSS) tool was utilized for the milling test on CNC Vertical Milling machine (VMC C600). The Central Composite Face Centered Design was used to implement the response models using RSM. Fifteen sets of experiment were taken by incorporating ½ fractions, 1 axial point, 6 center points and 1 replicated factorial point. The Table 1 presents the machining process parameter ranges selected to form design matrix. To achieve a desired response the trial experiment were performed in setting the process parameters and are shown in The Table 2.

Table 1 **Process parameters**

Process parameters	Units	levels		
		-1	0	1
Cutting speed (C_s)	mm/min	80	120	160
Feed rate (f)	mm/rev	0,02	0,04	0,06
Axial depth of cut (a_p)	mm	1	2	3

Standard metallography techniques were followed using 200 X magnification on optical microscope (OM). The machined sample piece was grinded using the emery paper of grind size 400, 600, 800, 1200 and 1500 followed by 6 micro-metre diamond paste, etched at room temperature with Keller's reagent (95 ml distilled water, 2,5 ml HNO_3, 1,5 ml of HCl and 1,0 ml of HF) and immersed up to 20 s to achieve better contrast on the surface. The micro-hardness of the machined surface was tested by Vicker's micro-hardness tester by applying a load of 50 gf with a time interval of 5 seconds. The experiment was repeated thrice to minimize the error and the average micro-hardness was recorded and is tabulated in

Analysis of variance for micro-hardness

Analysis of the machining variables on micro-hardness was carried out by Analysis of Variance (ANOVA). Total numbers of experiments with their levels are tabulated in ANOVA table formulation. 'F' value was found to be more than '1' which indicates the process variable influences the responses. It has been observed from the Table 3 that, 'F' value of feed (3,2) is larger value than the F' value of speed (2,22) for micro-hardness. From the tabulated result it is evident that the feed rate has significant effect on micro-hardness value. The R^2 and R^2(adj) are 90 % and 80 % values conforms the developed micro-hardness model is significant.

Table 2 **Design of experiments with measurement of micro-hardness**

C_s / m/min	f / mm/rev	a_p/ mm	MH/ HV
80	0,02	1	122,5
120	0,04	2	127,2
160	0,04	2	125,1
120	0,02	2	120,1
120	0,06	2	126,7
120	0,04	1	118,8
80	0,04	2	130,6
120	0,04	3	118,7
160	0,02	3	115,4
120	0,04	2	126,6
120	0,04	2	127,8
80	0,06	3	131,2
120	0,04	2	130,8
160	0,06	1	118,3
120	0,04	2	126,8

Table 3 **ANOVA**

Source	Sum of Squares	DF	Mean Square	F-value
C_s	15,13	1	15,13	2,22
f	21,78	1	21,78	3,2
a_p	0,005	1	0,005	0,0007
Residual	34,03	5	6,81	-
Total	365,56	14	-	-

RESULTS AND DISCUSSION

Microstructure and micro-hardness

During the machining process, microstructure alternation has taken place due to the thermal softening and strain hardening effects. Figure 2a-b potrays 200 X optical image of pressure die casted LM 25 alloy under 2μm in scanning electron microscope (SEM). Figure 3a-b potrays 200 X optical image under 100 μm in scanning electron microscope (SEM) of the perpendcular cross section to the milled surface under the cutting parameters of Cs = 80 m/min, f = 0,06 mm/rev, a_p = 3 mm. The resizing and reshaping of the grains are the changes in the microstucture formed during th cutting process or these phase transformation can be due to thermal effects. Based on the selected cutting parameters the intensity can be varied. The intensity of this influence can vary based on the selected cutting parameters. Typical surface micrograph before and after high speed cutting is examining surface micrographs Figures 2 a-b. During the high speed end milling of LM25 alluminium alloy

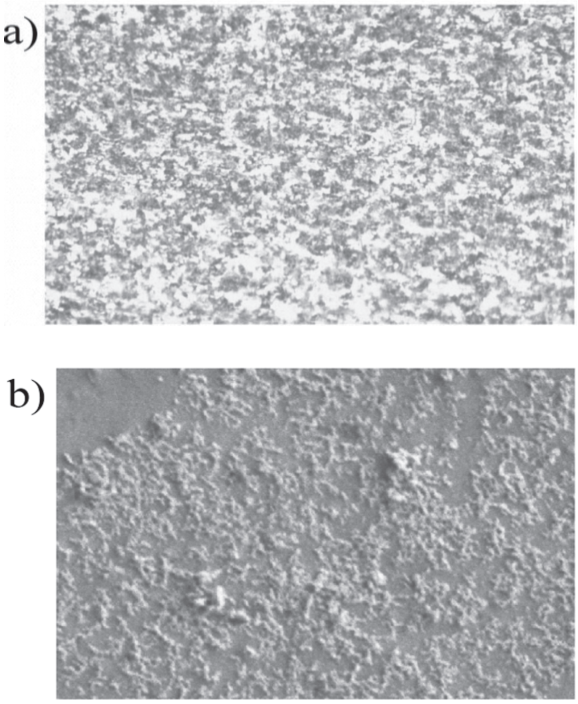

Figure 2 a-b Microstructure (a) and SEM (b) images of pressure die casted LM25 alloy

no change in recrystallization and this is evident from the Figures 3 a-b

On analyzing the machined surface the extra-large grain structure are found. Due to insufficient time on cutting process, it is evident that this grain structure has not occurred after the recrystallization.

Therefore, in improving the micro-hardness plastic deformation and strain hardening plays a major role.

It is evident from Figure 4, when the axial depth of cut is between the range 1,75 and 2,78 mm there is increase in micro-hardness with decrease in cutting speed. The friction increases at higher depth of cut which considerably induces the metallurgical changes on the machined surface which reduces the hardness on thermal softening.

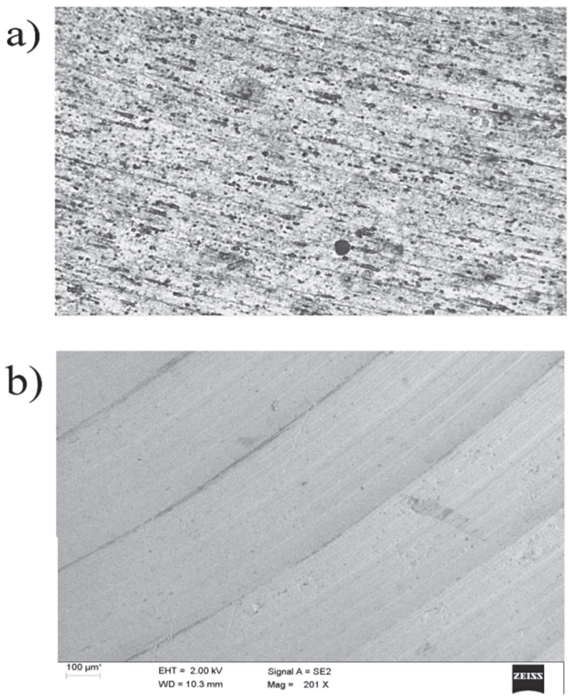

Figure 3 Microstructure (a) and SEM (b) images of milled LM25 alloy

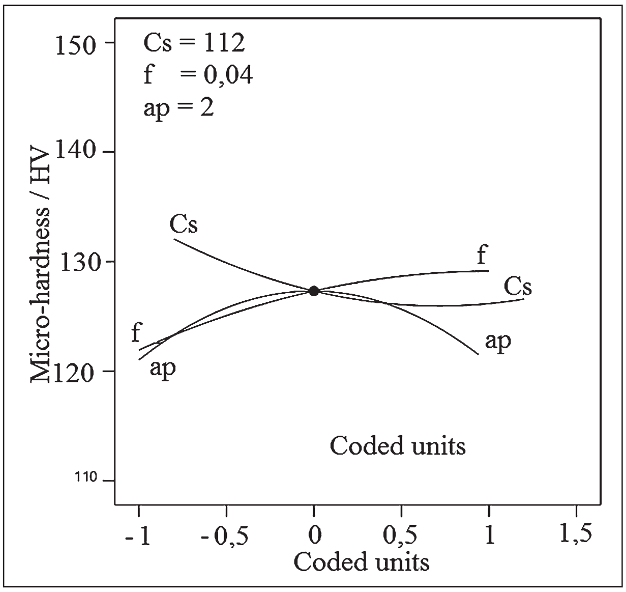

Figure 4 Perturbation effects of C_s, f, a_p Vs. MH

It is evident from the Figure 5 counterplot and ANOVA Table 3, the effect of feed rate is highly influenced by the micro-hardness. Increase in feed rate increases the micro-hardness directly. But from the Figure 4 it is evident that the micro-hardness is inversely related to cutting speed. Increase in cutting speed decreases the micro-hardness. At a lower cutting speed between (80 – 100 m/min) the micro-hardness have attained a good value. The micro-hardness is improved from (128 - 131 HV) for the lower cutting speed and for range of feed rate between 0,02 to 0,03 mm/rev. The micro-hardness decreases for the range of cutting speed between 140 and 160 m/min with lower feed rate.

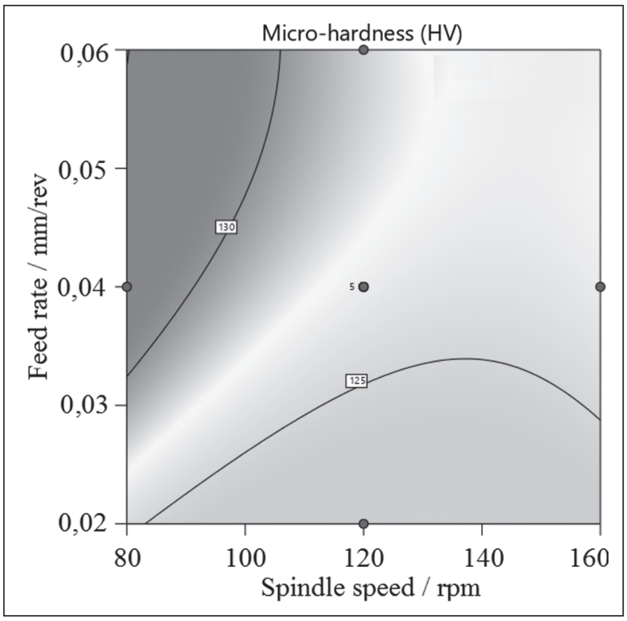

Figure 5 Counterplot effect

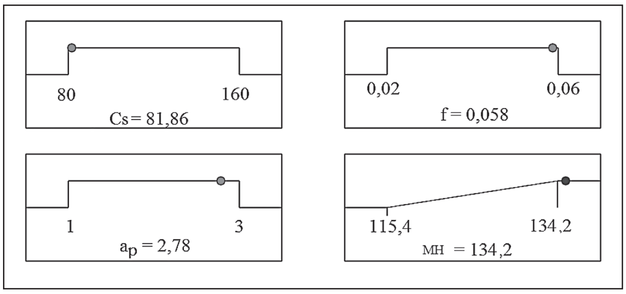

Figure 6 Optimized values in ramp using desirability function

Figure 6 shows the single objective optimal values for achieving of higher micro-hardness using desirability function. The optimal values such as Cs (81,86 m/min), f(0,058 mm/rev), ap(2,78 mm) gives higher value of MH(134,2 HV).

CONCLUSION

Following conclusions are made by observing the investigation.

- The R^2 and R^2(adj) are 90 % and 80 % values conforms the developed micro-hardness model is significant.
- The perturbation effect plot gives a clear evident maximum micro-hardenss can be obtained when the cutting speed (Cs) is in the range of 80 - 100 m/min, feed rate (f) between 0,02 to 0,03 mm/rev and axial depth of cut (a_p) between the range of 1,75 and 2,75 mm
- The optimal values such as C_s (81,86 m/min), f(0,058 mm/rev), a_p(2,75mm) gives higher value of MH(134,2 HV) using desirability approach.

REFERENCES

[1] R. LMalghan, M C. K.Rao, S, ArunKumar, Shrikantha S Rao, M. A Herbert. Machining Parameters Optimization of AA6061 Using Response Surface Methodology and Particle Swarm Optimization. International Journal of Precision Engineering and Manufacturing 19 (2018) 5, 695-704.

[2] W. Zhang, X. Wang, Y. Hu, S. Wang. Predictive modelling of microstructure changes, micro-hardness and residual stress in machining of 304 austenitic stainless steel. International Journal of Machine Tools and Manufacture 130(2018), 36-48.

[3] M. Salahshoor, Y.B. Guo. Surface Integrity of Biodegradable Orthopedic Magnesium-Calcium Alloy Processed by High Speed Machining. Medical Device Materials VI Proceedings from the Materials and Processes for Medical Devices Conference August 8–10, (2011), 125-131.

[4] L. Qiang, G. Ya-dong, C. Ming, L. Ming-jun. Research on surface integrity in milling Inconel718 superalloy. The International Journal of Advanced Manufacturing Technology 92(2017) (1-4), 1449-1463.

[5] Hassanpour, H., Sadeghi, M. H., Rezaei, H., & Rasti, A. (2016). Experimental study of cutting force, microhardness, surface roughness, and burr size on micromilling of Ti6Al4V in minimum quantity lubrication. Materials and Manufacturing Processes 31(13), 1654-1662.

[6] N. Zeelanbasha, V. Senthil B. R. Senthil Kumar, An Integrated Approach of RSM and MOGA for the Prediction of Temperature Rise and Surface Roughness in the End Milling of Al 6061-T6. Transactions of FAMENA 42 (2018)3, 115-128.

[7] E. Hazir, T. Ozcan. Response Surface Methodology Integrated with Desirability Function and Genetic Algorithm Approach for the Optimization of CNC Machining Parameters. Arabian Journal for Science and Engineering (2018) 1-15.

[8] A. Labidi, H. Tebassi, S. Belhadi, R. Khettabi, M. A. Yallese. Cutting Conditions Modeling and Optimization in Hard Turning Using RSM, ANN and Desirability Function. Journal of Failure Analysis and Prevention 18(2018) 4, 1017-1033.

[9] A.Khorasani, M.R.Syazdi. Development of a dynamic surface roughness monitoring system based on artificial neural networks (ANN) in milling operation. The International Journal of Advanced Manufacturing Technology 93(2017) 1-4, 141-151.

[10] K. Shi, D. Zhang, J. Ren. Optimization of process parameters for surface roughness and microhardness in dry milling of magnesium alloy using Taguchi with grey relational analysis. The International Journal of Advanced Manufacturing Technology 81 (2015) 1-4, 645-651.

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